MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2017/2018

EME4016 – HEAT TRANSFER
(ME)

2 MARCH 2018
9.00 a.m - 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of six pages including the cover page and appendix.
2. Answer ALL four questions. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].
3. Write all your answers in the Answer Booklet provided.

Question 1

(a) Show, by deriving from the Fourier law, that an expression for the thermal resistance of a cylindrical shell is $\frac{1}{2\pi kL} ln\left(\frac{r_o}{r_i}\right)$, where symbols have their usual meanings.

[5 marks]

(b) Find the steady-state, no heat source, one-dimensional temperature distribution $T(r)$in a long cylindrical shell of inner radius r_i and outer radius r_o, if the inner surface is kept at temperature T_i, the outer temperature kept at T_o. The thermal conductivity and the length of the cylindrical shell are unknown.

[8 marks]

(c) A long solid shaft 1 without heat source has thermal conductivity k_1 and radius r_1. It is covered with a heating solid layer 2, of thermal conductivity k_2 and external radius r_2, with heat generation of $\dot{q}$. The outside surface of the heating layer is maintained at 0°C. The objective is to find the steady temperature in shaft 1.

For this problem the thermal resistance circuit concept is not applicable, and the problem must be solved using the conduction equation.

(i) Write down the appropriate conduction equation for the shaft 1, using T_1 to denote its temperature. Then solve the equation for a general solution of T_1.

(ii) Write down the appropriate conduction equation for the layer 2, using T_2 to denote its temperature. Then solve the equation for a general solution of T_2.

(iii) The general solutions in (i) and (ii) involve 4 integration constants, which can be found by using the following boundary conditions: At $r = 0$, T_1 is finite. At $r = r_1$, $T_1 = T_2$. At $r = r_1$, the heat transfers are the same across the boundary. At $r = r_2$, the temperature is known. Hence or otherwise, obtain the temperature in shaft 1.

[12 marks]

Note: Take the 1-D conduction equation in cylindrical coordinates as

$$\frac{k}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \dot{q} = 0.$$

Continued...

Question 2

(a) Distinguish between "surface resistance" and "space resistance" in the analysis of thermal radiation networks.

[4 marks]

(b) Two large parallel plates 1 and 2, at temperatures $T_1 = 800\ K$ and $T_2 = 600\ K$, have emissivities $\varepsilon_1 = 0.5$ and $\varepsilon_2 = 0.8$, respectively. The surface area is one square metre each.

(i) Draw the thermal network and find the net heat transfer by radiation between the plates.

(ii) A radiation shield, labelled as 3, is placed between the two plates. The shield has emissivity $\varepsilon_{3-1} = 0.1$ on the side facing plate 1, and has emissivity $\varepsilon_{3-2} = 0.05$ on the side facing plate 2. Draw the thermal network and calculate the heat transfer between plates 1 and 2.

[15 marks]

(c) Consider a special case of (b) (ii), where half of the radiation shield area is perforated uniformly with small round holes, other conditions remaining the same. Draw the thermal network for this situation, and calculate the heat transfer between the plates 1 and 2.

[6 marks]

Note: Take the Stefan-Boltzmann constant to be $5.67 \times 10^{-8}\ W/m^2 \cdot K^4$.

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Question 3

Consider parallel flow of atmospheric air over a 1.5 *m* long isothermal flat plate of temperature 400 *K*. The air has a temperature of 300 *K* and velocity of 2 *m/s*.

(a) Evaluate the relevant thermophysical properties of air at the film temperature.
[3 marks]

(b) Calculate the local heat transfer coefficient at the trailing edge of the plate.
[8 marks]

(c) Calculate the local heat flux at the trailing edge of the plate if there is an unheated starting length of 1 *m*.
[9 marks]

(d) Estimate the local heat transfer coefficient at the leading edge of the plate, with and without the unheated starting length of 1 *m*. Justify your answer with appropriate calculation.
[5 marks]

Table Q3: Convection heat transfer correlations

Correlation	Conditions
$Nu_x = 0.332\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}$	Laminar flow
$Nu_x = 0.0296\,\mathrm{Re}_x^{4/5}\,\mathrm{Pr}^{1/3}$	Turbulent flow
$Nu_x = \dfrac{Nu_x\big\|_{\xi=0}}{\left[1-(\xi/x)^{3/4}\right]^{1/3}}$	Laminar flow
$Nu_x = \dfrac{Nu_x\big\|_{\xi=0}}{\left[1-(\xi/x)^{9/10}\right]^{1/9}}$	Turbulent flow

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Question 4

(a) A 0.5 *m* × 0.5 *m* hot surface at 100 °*C* is cooled by attaching 2500 aluminum pin fins with thermal conductivity of 240 *W/m·K*. These circular pin fins are 50 *mm* long with 5 *mm* diameter. The surrounding temperature is 25 °*C* and the heat transfer coefficient on the surfaces is 50 $W/m^2{\cdot}K$. The fin efficiency is defined as

$$m = \sqrt{4h/kD}$$
$$L_c = L + D/4$$
$$A_{\text{fin}} = \pi D L_c$$
$$\eta_{\text{fin}} = \frac{\tanh mL_c}{mL_c}$$

(i) Determine the total heat transfer rate from the hot surface.

[10 marks]

(ii) As a research engineer, you are asked to improve the fin efficiency without incurring extra material costs. One of your colleagues suggested to replace the circular pin fins with square pin fins. Please state if the square pin fins will improve the fin efficiency. Justify your answer without calculating the fin efficiency.

[5 marks]

(b) A concentric tube heat exchanger with an area of 30 m^2 is having a hot fluid with specific heat of 3500 *J/kg·K* flowing at a rate of 2 kg/s and temperature of 80 °*C*. The hot fluid is to be cooled with chilled water supplied at the same mass flow rate with specific heat of 5000 *J/kg·K* at an inlet temperature of 15 °*C* and an outlet temperature of 50 °*C*.

(i) Determine the outlet temperature of the hot fluid.

[4 marks]

(ii) Is the heat exchanger operating in parallel flow or counter flow? Sketch the temperature distribution for the heat exchanger.

[4 marks]

(iii) Calculate the maximum possible heat transfer rate for the heat exchanger.

[2 marks]

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APPENDIX: Thermophysical Properties of air at Atmospheric Pressure

T (K)	ρ (kg/m^3)	c_p (kJ/kg · K)	$\mu \cdot 10^7$ (N · s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^6$ (m^2/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709
850	0.4097	1.110	384.3	93.80	59.6	131	0.716
900	0.3868	1.121	398.1	102.9	62.0	143	0.720
950	0.3666	1.131	411.3	112.2	64.3	155	0.723
1000	0.3482	1.141	424.4	121.9	66.7	168	0.726
1100	0.3166	1.159	449.0	141.8	71.5	195	0.728
1200	0.2902	1.175	473.0	162.9	76.3	224	0.728
1300	0.2679	1.189	496.0	185.1	82	238	0.719
1400	0.2488	1.207	530	213	91	303	0.703
1500	0.2322	1.230	557	240	100	350	0.685
1600	0.2177	1.248	584	268	106	390	0.688
1700	0.2049	1.267	611	298	113	435	0.685
1800	0.1935	1.286	637	329	120	482	0.683
1900	0.1833	1.307	663	362	128	534	0.677
2000	0.1741	1.337	689	396	137	589	0.672
2100	0.1658	1.372	715	431	147	646	0.667
2200	0.1582	1.417	740	468	160	714	0.655
2300	0.1513	1.478	766	506	175	783	0.647
2400	0.1448	1.558	792	547	196	869	0.630
2500	0.1389	1.665	818	589	222	960	0.613
3000	0.1135	2.726	955	841	486	1570	0.536

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